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Alberta ENERGY

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Coal Preparation Research in Alberta

Projects supported in part
by the Alberta/Canada
Energy Resources
Research Fund

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Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal and conventional energy resources, as well as energy conservation and renewable energy. Program administration is provided by staff within the Scientific and Engineering Services and Research Division of Alberta Energy.

In recognition of the importance of coal to Alberta's economy, the Alberta Office of Coal Research and Technology was established in 1984 within Alberta Energy and Natural Resources (now Alberta Energy). Its primary purpose is to encourage the development and application of new technologies related to Alberta coals. The Office provides funding contributions to research and development projects in industry, academic institutions and other research establishments and monitors their progress in an overall program of improving the production, transportation and marketability of Alberta coals.

In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to page 22.

Coal Preparation Research in Alberta

Deposits of low-rank bituminous and subbituminous coals located beneath the plains and foothills of Alberta constitute half the coal in Canada. Therefore, these deposits are a major energy storehouse, capable of making a significant contribution to Canada's overall energy supply and generating substantial earnings every year from local and overseas sales of coal.

More than 90 per cent of the electricity produced in Alberta is generated by minemouth power plants fuelled by subbituminous coals. These coals are used as-mined, without beneficiation. Such lower-rank coals, even if beneficiated, do not contain sufficient heating value to justify transportation to distant markets.

Bituminous coals from the foothills are consumed in thermal power plants in central Canada and overseas. These coals must undergo comprehensive beneficiation, primarily as an economic necessity to reduce transport costs per unit of energy.

This degree of coal preparation is necessary for several reasons. First, run-of-mine coal comprises coal, sandstone, clay from shales and moisture. In Alberta's case, bituminous coals are found in environments that differ from those associated with coal of similar rank in other coalfields. Because the shale is not as easily removed as elsewhere, and the clay is often present in thin bands that cannot be removed by selective mining, total washing of the coal is often necessary. This, however, must be followed by drying because the moisture content must be reduced to certain specified levels. This is an expense not necessarily borne by coal producers in other coal-supply areas.

Secondly, while it is desirable to obtain a prepared coal having an ash content of less than 10 per cent, this is difficult to accomplish because the low-ash components common to coals from other coalfields are absent from Alberta's bituminous coals.

Finally, cleaning requirements can vary considerably for coal extracted from different locations within a single deposit, depending upon the occurrence of thin bands of clay. Furthermore, the clay can penetrate fissures in the coal structure, requiring considerable effort to remove it. This must be done, or else high ash values will result. Washing, however, usually causes the clay to expand within the fissures, resulting in disintegration of coal lumps into fines (fine particles smaller than 0.6 mm in diameter). In turn, this finely divided product must be thermally dried to lower the moisture content. The large volumes of rejects (tailings) produced during washing must subsequently be dewatered to minimize the need for tailings disposal ponds.

This degree of coal preparation, therefore, contributes substantially to the overall costs of producing acceptable coal products, thus reducing the advantage of relatively inexpensive mining methods that can be used in Alberta. For example, preparation costs represent 25 per cent of total production costs and are twice those for some comparable coals from other countries. Because the principal objective is to provide clients with a fuel having a specified quantity of energy at the lowest possible cost, there is considerable interest in lowering the costs of preparing thermal bituminous coals for market.

While subbituminous coals having an ash content of 10 to 15 per cent can be used directly to generate electricity in Alberta, large amounts of this type of coal having an ash content of approximately 20 per cent are available. If these coals could be upgraded at a reasonable cost, they could be used in out-of-province power plants, or be exported or converted to synthetic crude oils.

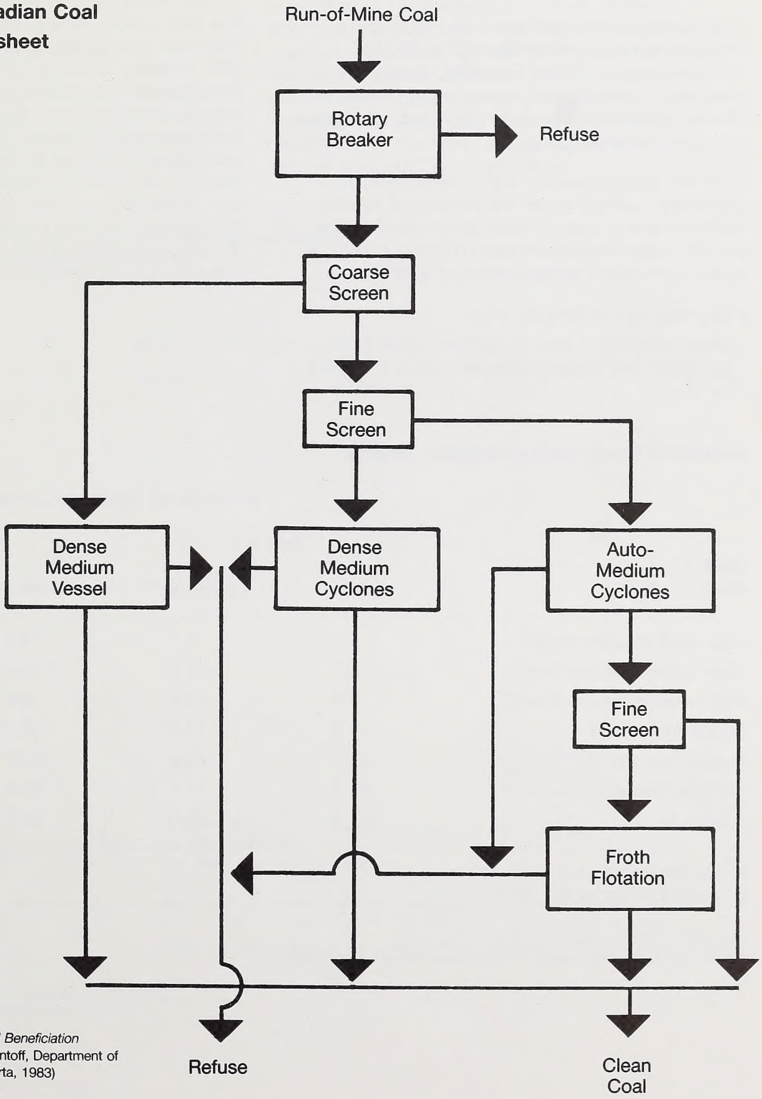
Therefore, developing improved coal beneficiation and upgrading systems represents a technical and economic challenge for producers of western Canadian coal; it is regarded as a key component in maintaining a cost-competitive position in Canadian and overseas coal markets. Consequently, several coal preparation research projects were undertaken in Alberta and funded in part by the Alberta/Canada Energy Resources Research Fund (A/CERRF), as administered by the Alberta Office of Coal Research and Technology.

Coal Preparation Research

In the early 1980s, the Coal Mining Research Company (previously the Coal Mining Research Centre, CMRC) began a coal preparation research program to address several problems posed by the characteristics of western Canadian subbituminous and bituminous thermal coals. CMRC was created to deal with certain areas of coal mining and preparation research not being addressed by others. Also, its programs avoided duplicating existing investigations by other coal research agencies. Consequently, research on the cleaning of bituminous coking coals was not included in CMRC's mandate because these particular coals are being investigated by the Canada Centre for Mineral and Energy Technology (CANMET).

Because moisture is the principal inert substance associated with lower-rank coals, and conventional washing processes can increase the water content, it was decided that CMRC's coal preparation research program would focus initially on thermal drying of raw coal, followed by dry cleaning of the product.

A Typical Western Canadian Coal Preparation Plant Flowsheet



(Source: *Modelling and Control of Coal Beneficiation Unit Operations,* Plitt, L.R. and B.C. Flintoff, Department of Mineral Engineering, University of Alberta, 1983)

Coal Moisture Measurements

At the beginning of CMRC's program, it was realized that there are anomalies in the terminology and methods used to determine coal moisture. For example, between two testing organizations that have developed the most widely used standard methods for moisture measurements, there are 11 standards incorporating 20 variations in sampling and laboratory techniques. Furthermore, these procedures, developed by the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO), are based primarily on analytical research relating to high-rank coal.

To confirm results presented in the technical literature and to compare the ASTM and ISO methods, seven western Canadian coals were analysed for moisture by several methods at the Alberta Research Council, the University of Regina and Cyclone Engineering Ltd.

From the analysis results and in consideration of published cautions about the analysis of reactive, oxidation-prone coals, it was recommended that the ISO weight-loss-in-nitrogen method should be used for analytical determination of coal moisture.

It was also recommended that:

- when analysing a new or unknown coal, both the direct and indirect nitrogen methods should be used;
- distillation methods are not recommended for moisture determination;
- the commonly used forced-air drying oven using undried air is not suitable for analytical moisture determination, but is acceptable for process control testing; and
- moisture definitions as in ASTM D121 should be used.

Associated with the choice of standard moisture measurements to be used at CMRC, were standard procedures that were similarly adopted for determining the performance of dewatering equipment.

The same coals used in the comparative moisture tests were investigated for dewatering characteristics after washing. A closely sized (4 x 8 mesh) sample of each coal was soaked in water and allowed to drain under standardized conditions. Then the moisture was determined by various methods. In each case, it was found that the difference between the total moisture and the equilibrium moisture was essentially constant. This led CMRC investigators to conclude that the ASTM definition of free moisture should be used to determine the performance of mechanical dewatering equipment.

Results of Comparative Moisture Testing

	Determined Moisture Content %			
	Test #1		Test #2	
Coal Rank	Air[1]	Nitrogen[2]	Air[1]	Nitrogen[2]
Low-volatile bituminous	1.3	1.3	0.5	0.6
High-volatile bituminous C	7.7	8.2	8.0	9.0
High-volatile bituminous C	9.9	10.5	9.8	10.2
Subbituminous B	17.0	17.5	17.3	17.6
Subbituminous C	22.7	23.2	22.6	23.0
Subbituminous C	21.3	21.7	20.0	21.2
Lignite A	32.5	32.9	32.9	32.3

1. Method similar to ASTM D 3302
2. Method similar to ISO 589 B

(Source: *Beneficiation of Western Canada's Low Rank Coals,*
Butcher, S.G., Coal Mining Research Company Report 82/18-T, March 1982)

Drying Characteristics of Western Canadian Coals

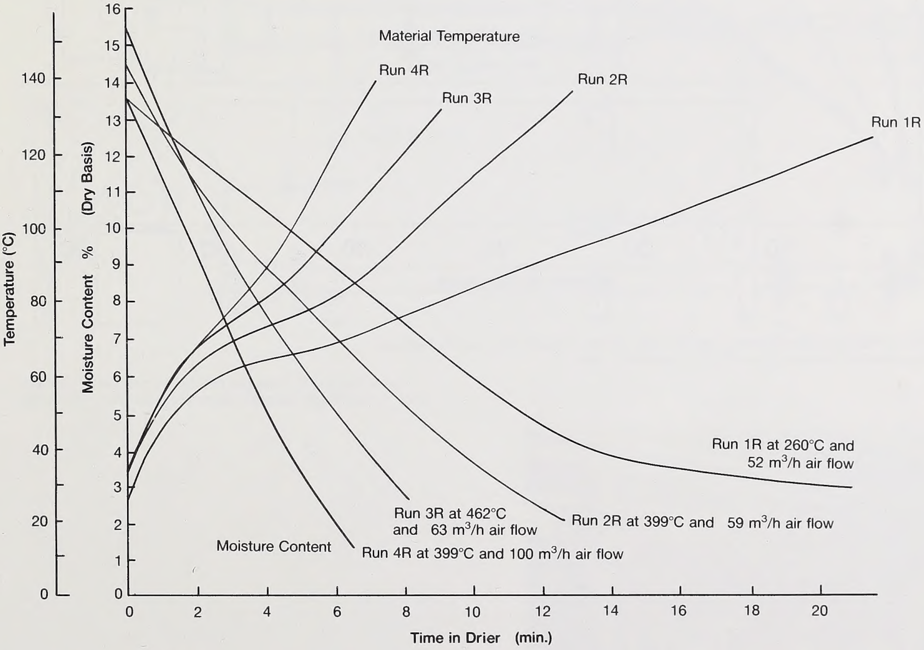
Some experiments were initiated to obtain detailed information about the drying characteristics of western Canadian coals. This work was prompted by the need to remove moisture from coals for several reasons:

- to reduce freight charges for long-distance shipments;
- to reduce heat losses during combustion;
- to meet client specifications;
- to facilitate handling in process equipment;
- to achieve maximum capacity at other steps in a process or to improve quality; and
- to condition coal for further treatment.

Moisture in coal is held in several forms, ranging from surface moisture to water of hydration within the coal structure. It may be found on the surface, in macropores and in interstitial spaces. Because there is a gradual increase in both the average pore size and total pore volume as coal rank increases, it was reasoned that the rate of moisture release from the porous structure of coals during drying should vary with coal rank. Such a relationship could provide a method for predicting product moisture.

To establish whether this relationship existed, 44 samples of coal varying in rank from lignite A to low-volatile bituminous, were tested for moisture content and dried in a bench-scale Brabender SAS-H drier. Twenty-gram samples of each coal, including some that had been oxidized, were dried at three temperatures: 100°, 150° and 200°C. In addition to measurements of total moisture, laboratory analyses were made of equilibrium moisture (as defined by ASTM) and ash content. The work required development of a standard test procedure to prepare and precondition the test samples. Also, care was taken to prevent loss of moisture from the time coal samples were collected at mine sites until they were dried.

Drying Characteristics of 25 mm x 0 mm Raw High-Volatile Bituminous Coal in Batch Roto-Louvre Drier



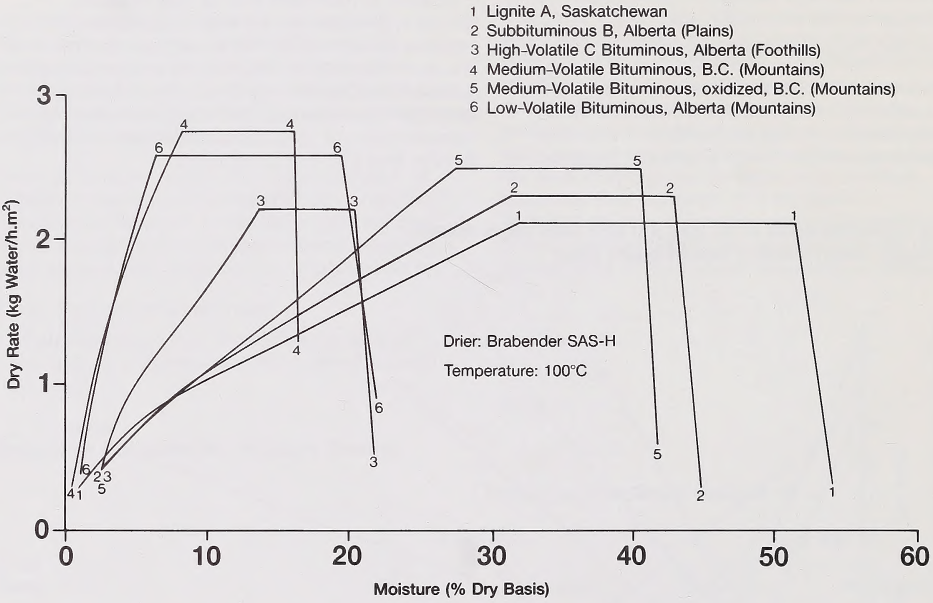
(Source: *Thermal Drying of a Raw Western Canadian Low Rank Coal*, Rashid, M.A., Coal Mining Research Company Report 82/24-T.)

Typical drying curves for each coal sample were prepared. From these data, rate-of-drying curves were prepared. These showed that equilibrium moisture and moisture release characteristics were directly related to coal rank and could be interpreted from drying-rate curves.

The study also showed that by controlling the rate of drying, coal moisture could be reduced below the equilibrium moisture value without incurring an abnormal increase in dried product temperature.

When coal is oxidized, it apparently becomes more hydrophilic (having an affinity for water). This tendency was borne out by the observation that samples of medium-volatile bituminous coal that had undergone various degrees of oxidation showed an increase in equilibrium moisture content as the degree of oxidation increased. The drying characteristics of oxidized higher rank coals were similar to those of subbituminous coals.

Rate-of-Drying Curves



(Source: *Drying Characteristics of Western Canadian Coal, Volume 1,* Rashid, M.A. and P.S. McIntosh, Coal Mining Research Company, Report 83/69-T, September 1985.)

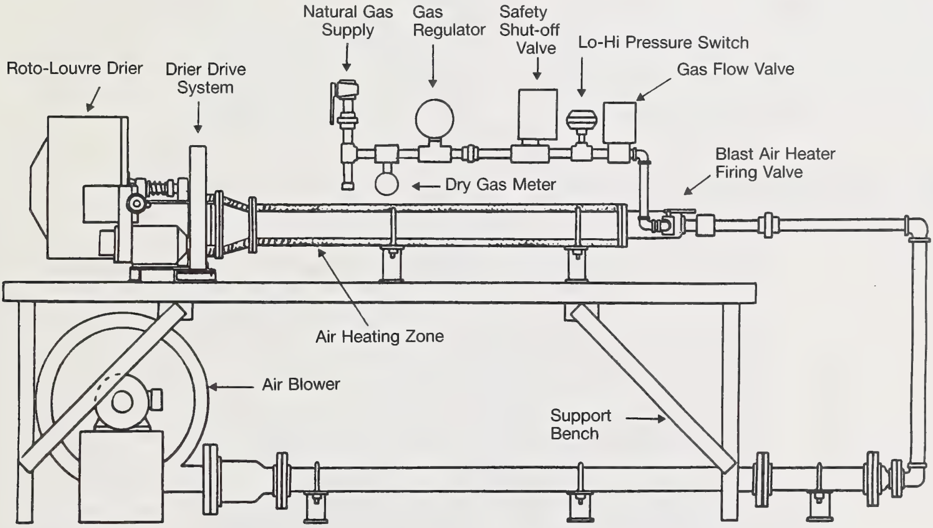
Pilot-Scale Drying Studies

In late 1981, a high-volatile bituminous run-of-mine coal containing 30 per cent clay and 20 per cent moisture was dried under various conditions in a batch Roto-Louvre drier, a continuous fluidized-bed drier and a pilot-scale Roto-Louvre drier operated by FMC in Colmar, Pennsylvania. An abnormally poor batch of coal was chosen for these tests to meet the following objectives:

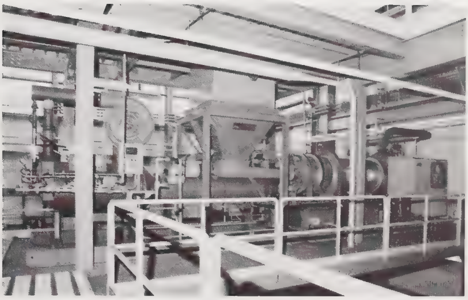
- to investigate the drying characteristics of raw coal with a significant clay content;
- to identify the problems associated with drying this material in the coal industry; and
- to determine the degree of coal size degradation when drying raw coal to various levels of product moisture.

The experience gained from this work led to the design and construction of CMRC's pilot-scale coal facility at the Coal Research Centre, Devon. It includes a bench-scale drier used to determine drying curves and capable of handling batches of up to 20 kg (44 lb.), a 60 kg/h (132 lb./hr.) fluidized-bed process development unit and a 1 t/h continuous Roto-Louvre drier. The latter can handle normal, product-sized coal having a top size of 50 mm (2 in.). It is mounted on skids to permit field use in addition to pilot plant work.

Bench-Scale Batch Roto-Louvre Drier used at The Coal Mining Research Company



(Source: *Thermal Drying Pilot Units, Operating Instructions Manual,* Rashid, M.A., Coal Mining Research Company Report 85/65-T, 1986)



One-tonne-an-hour Roto-Louvre drier used to dry product-sized coal at the Coal Mining Research Company.

Dry Cleaning

On behalf of CMRC, Norwest Resource Consultants Ltd. of Calgary reviewed the state-of-the-art in coal dry-cleaning processes in 1980. At the time, it was found that dry-cleaning processes were being used to clean approximately one per cent of all beneficiated coal, as opposed to 10 per cent in the 1960s. This decline was said to be caused by dust control measures in mining operations that produced coals having a higher surface moisture.

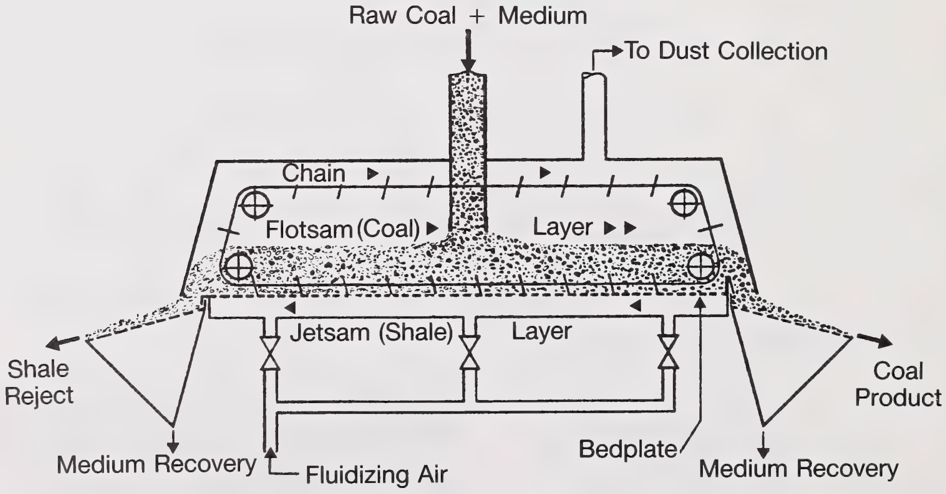
Most commercial-scale dry-cleaning processes separate coal from other mineral matter on the basis of differences in specific gravity. In this respect, they are similar to wet processes, except they use air as the separating medium instead of water. However, their use tends to be limited to dry, coarse, easily cleaned coal.

In reviewing the various types of dry-cleaning devices that have been tried, and in evaluating separation efficiencies, the contractor concluded from theoretical considerations of particle physics that air jigs or fluidized-bed processes employing dry, dense media should be the most efficient.

Representing the latter type of process was a system called the Counter-Current Fluidized Cascade (CFC), invented by J.M. Beeckmans of the University of Western Ontario in London, Ontario. It is a novel dry separation process for mixed granular solids and is capable of separating particles of relatively large size and density difference. Consequently, approximately 150 tests were performed using a laboratory-scale unit and surface-dried low-rank coals of various size distributions.

The CFC apparatus used in this work measured 190 mm (7.5 in.) wide, 609 mm (24 in.) deep and either 5 563 mm (219 in.) or 3 708 mm (146 in.) in length. Separation was achieved by a process known as vertical partial segregation, which was magnified in the horizontal direction by the movement of a baffled chain through the lower strata of the raw coal/medium mixture toward the reject (jetsam) end of the device. This induced a counterflow of upper strata solids in the opposite direction toward the product (flotsam) end. While this occurred, pressurized air was forced upward through the coal/medium mixture.

Counter-Current Gas Fluidized Cascade Device

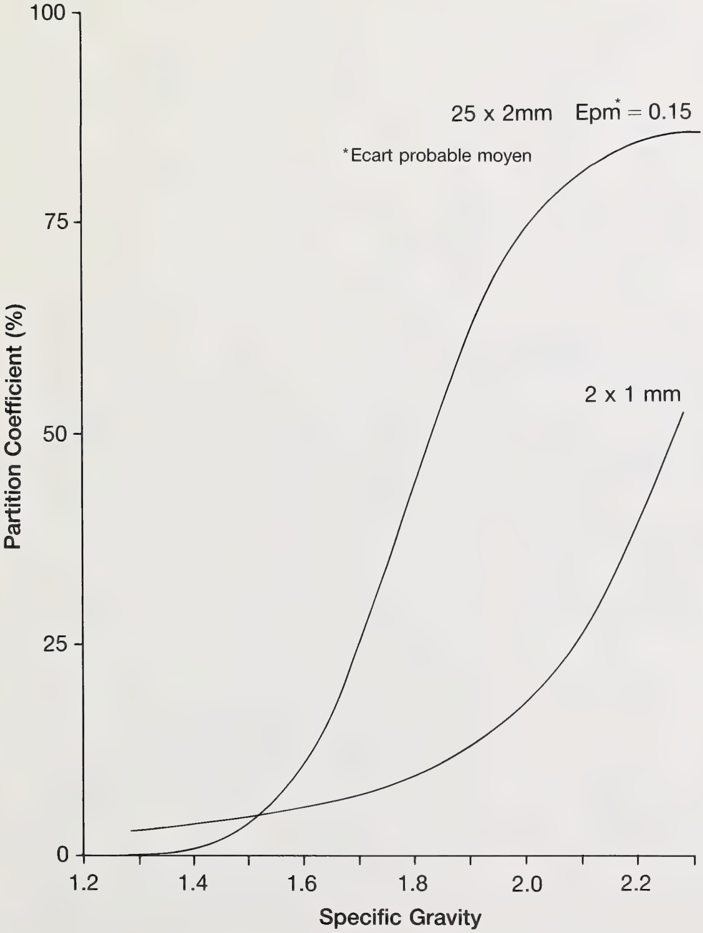


(Source: *Dry Cleaning of Coal in The Counter-Current Fluidized Cascade,* Germain, R.J., S.G. Butcher and J.M. Beeckmans, Coal Mining Research Company Report 82/05-T, April 1982)

Analysis of the laboratory test results showed that separations were as effective as those using conventional Baum jigs, and were better than with air jigs. A regression analysis of the results suggested that acceptable cleaning efficiencies should be achievable at 30 tonnes/hour/metre of machine width. In subsequent tests using a five tonne/hour/metre pilot-scale unit, the laboratory results were confirmed at low feed rates, but cleaning efficiencies were lower than expected at the higher feed rates needed for commercial operations.

Partition Curves

CFC Treatment of 25 x 1 mm Coal Using Limestone/Magnetite Fluidizing Medium



(Source: *Dry Cleaning of Coal in The Counter-Current Fluidized Cascade,* Germain, R.J., S.G. Butcher and J.M. Beeckmans, Coal Mining Research Company Report 82/05-T, April 1982.)

Representative Test Results Using a Laboratory Scale Counter-Current Gas Fluidized Cascade Device

Run No.	Raw Feed Coal		Fluidizing Medium 0.6 x 0.125 mm	Performance Data		
	Size mm	Rate T/h-m		Size Fraction (mm)	Partition Density	Epm*
5#	20 x 0.8	1.0	limestone	20 x 6	(low)	(low)**
				6 x 0.8	1.56	0.18
9#	20 x 0.8	3.7	limestone	20 x 6	1.54	0.04
			+ hematite	6 x 0.8	1.81	0.20
115	3 x 0.6	7.7	fine coal	3 x 1	1.75	0.24
			+ magnetite	1 x 0.6	(2.19)	(0.42)**
129	25 x 0.8	5.1	limestone	25 x 2	1.84	0.15
			+ magnetite	2 x 1	(2.09)	(0.26)

Raw Feed Coal Rate is given in tonnes per hour per metre machine width.

# - Runs using 3 660 mm long cascade

* - Ecart probable moyen

** - Insufficient points to draw complete Partition Curves

(Source: *Novel Techniques Applied to The Beneficiation of Western Canadian Coals,* Mikhail, M.W., and S.G. Butcher, Coal Mining Research Company Report 82/03-T, January 1982)

Costs and Benefits of Alternative Coal Preparation Schemes

Western Canadian thermal coals shipped to Pacific Rim customers must satisfy the following, basic "as received" specifications:

Calorific Value	not less than 6 000 kcal/kg (10 800 BTU/lb.)
Ash Content	not more than 15 per cent
Moisture Content	not more than 12 per cent
Sulphur Content	not more than one per cent

Also, certain combustion characteristics must be satisfactory, depending on the furnace in which the coals will be burned.

While western Canadian coals easily satisfy the sulphur content specifications, foothills coals require comprehensive beneficiation, typically to nine per cent ash at nine per cent moisture content, to achieve the desired calorific value.

To help determine the economic value of alternative beneficiation schemes, the costs of preparing and delivering a given amount of a typical foothills coal were calculated. Then, the effects of various process changes on those costs were estimated.

The base case for comparison assumed the following: the use of a state-of-the-art mine and preparation plant; a product yield of 60 per cent; production of 3.5 million tonnes of coal a year at nine per cent ash and nine per cent moisture; and subsequent delivery of the product to a coastal terminal at Vancouver. This would provide sufficient coal for a 1 500 MW power plant.

In examining the results of these cost comparisons, it was apparent that lowering the moisture content of foothills coals from nine to seven per cent would probably result in lower product costs. While the costs of drying would increase, they would be more than offset by savings resulting from mining and cleaning less coal. It was recommended that substantial research and pilot-plant investigations into associated problems, such as dust control and methods for stabilizing the products, be undertaken prior to commercialization.

The comparisons also showed that commercial use of CFC dry-cleaning technology could lower the overall costs of producing coal by approximately $1.50 a tonne. However, the lower cleaning efficiencies from this process would make achievement of acceptable product quality more difficult.

While it was anticipated that coal preparation methods by themselves could not raise the calorific value of subbituminous coal to the level specified by overseas thermal coal customers, combinations of thermal drying, dry cleaning and adding oil or refinery residues should achieve the 6 000 kcal/kg specification at comparable or lower costs than with foothills bituminous coals. This observation underlined the importance of continued research on preparing and upgrading subbituminous coals.

Cost Comparisons: Conventional vs Alternative Coal Preparation Schemes

	Foothills Thermal Coals					Plains Thermal Coals		
	Base Case	Lower Moisture			New Dry[c] Cleaning Process	Drying[d] + Dry Clean	Drying[e] + Dry Clean + Oiling	Drying[f] + Dry Clean + Upgrading
		A[a]	B[b]	C[b]				
Specifications								
Ash %	9.0	9.5	10.0	11.0	12.0	10.0	9.5	9.7
Moisture %	9.0	8.5	8.0	7.0	6.0	8.0	7.6	5.4
Calorific Value kcal/kg	6 000	6 000	6 000	6 000	6 000	5 600[g]	5 860[g]	6 000
COSTS[h]								
Mining Costs	$ 23.55[i]	23.01[i]	22.55[i]	22.04[i]	23.64[i]	10.47[j]	9.95[j]	9.95[j]
Coal Handling and Loadout	$ 1.56	1.56	1.55	1.54	1.56	1.56	1.56	1.56
Washery	$ 3.21	3.17	3.11	3.09	–	–	–	–
Tailings Dewatering and Disposal	$ 1.83	1.81	1.77	1.73	–	–	–	–
Thermal Drier	$ 1.26	1.34	1.43	1.55	2.85	2.85	2.71	2.65
Drier Fuel (coal)	$ 0.30	0.35	0.39	0.51	–	–	–	–
Dry Cleaning	$ –	–	–	–	2.40	2.40	2.28	2.23
Oiling/Upgrading	$ –	–	–	–	–	–	11.63	6.98
Overhead (20%)	$ 6.34	6.25	6.16	6.09	6.09	3.46	5.63	4.67
Subtotal Minesite Costs	$ 38.05	37.49	36.94	36.55	36.54	20.74	33.76	28.04
Rail Transport and Ship Loading	$ 20.00	20.00	20.00	20.00	20.00	22.00	22.00	22.00
Total Cost, F.O.B. Vancouver	$ 58.05	57.49	56.94	56.55	56.54	42.74	55.76	50.04

[a] probably achievable by optimum drier operating conditions
[b] requires extensive testing to achieve
[c] using CFC dry separator
[d] thermal drying and dry cleaning
[e] same as d plus oiling, using oil at $30 per barrel
[f] same as e except oil refinery wastes are used
[g] calorific value is below specification level
[h] all costs in $/tonne of product
[i] mining costs of $14.13 per tonne run-of-mine (R.O.M.), corrected for variable preparation plant recovery rates (Base Case: 60%; others range from 60 to 64%)
[j] mining costs of $7.50 per tonne R.O.M. coal, corrected for a preparation plant recovery rate of 71.6%

(Sources: *Comparative Economics of Coal Preparation Processes,* Butcher, S.G. and P.S. McIntosh, Coal Mining Research Company Report 83/57-T, October 1983 and *Benefit/Cost Analysis of CMRC's Coal Preparation Research Program,* Butcher, S.G. and K. Barron, Coal Mining Research Company Report, 83/11-AD, February 1983)

Properties of Thermally Dried Coal

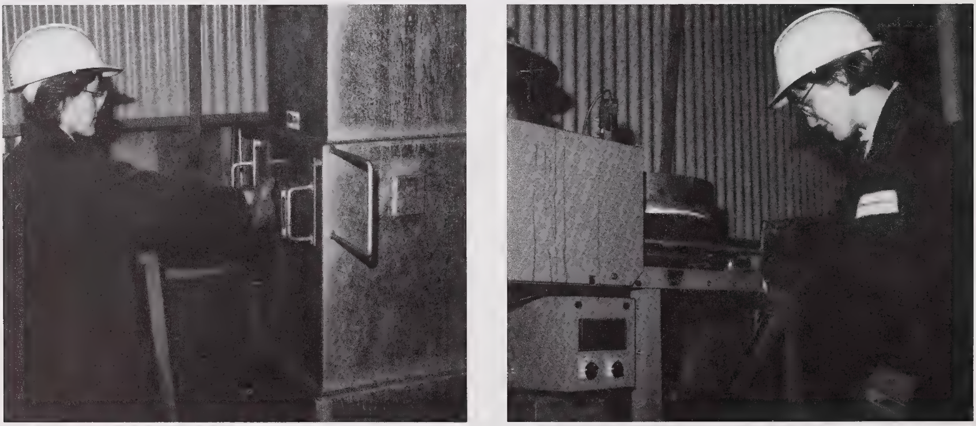
Soon after the pilot-scale Roto-Louvre drier was obtained by CMRC, four Alberta coals ranging in rank from subbituminous B to low-volatile bituminous were dried at five temperatures: 250°, 300°, 350°, 400° and 450°C at residence times of up to 15 minutes. This was a direct result of earlier work that identified a relationship between coal rank and moisture release characteristics. The pilot-scale work was undertaken to demonstrate that coals could be dried below their equilibrium moisture level on a continuous basis.

The study demonstrated that subbituminous B coal could be dried from 30 per cent total moisture to 10 per cent moisture at relatively low temperatures for the drying medium. High-volatile bituminous coal could be dried to less than its equilibrium moisture value. Medium-volatile bituminous coal could be dried to its equilibrium moisture value (two per cent), and low-volatile bituminous coal could be dried to a total moisture content of two per cent. All coals, however, become dusty below two per cent surface moisture.

Along with other physical attributes, handling characteristics vary from coal to coal. Knowing more about these properties is important because they can indicate, for example, at what moisture content a particular coal will be dusty or able to flow freely out of a hopper. An important handling characteristic is called flowability. It can be measured using the Durham Cone Test developed in Great Britain. Therefore, a Durham Cone apparatus was obtained to measure flowability properties of five Alberta coals at various product moisture levels. Dustiness and bulk density tests were also performed on the same coals.

Several conclusions were drawn from this investigation. Chief among them was the observation that flowability of fine coals improved as surface moisture was increased up to 2-3 per cent. For coarse coals, however, flowability decreased as surface moisture increased. Also, it was noted that an increase in surface moisture decreased coal dustiness. This applied regardless of coal rank or particle size distribution.

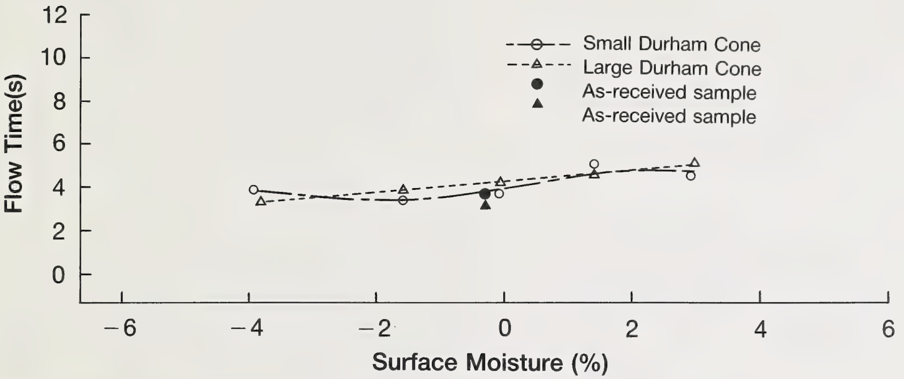
Associated with this work was the development of a coal dustiness test that is a modified version of the ASTM D547 test method. It was found that essentially the same test results could be obtained by using 6-kg samples instead of the usual 23-kg samples as required in the ASTM procedure.



An ASTM dustiness test cabinet (left) and a Durham Cone coal flow measurement apparatus are used at the Coal Mining Research Company in studies of coal drying and handling.

(Photos by Alberta Public Affairs Bureau)

Flow Times for Wetted Samples of an Alberta Coal



(Source: *Coal Handleability: The Durham Cone Test,* Germain, R.J. and D.F. Long, Coal Mining Research Company Report 85/67-T2, 1986)

Numerical Analysis of Process Yield Losses

Lower-than-expected yields from coal preparation plants are thought to be caused in part by continual fluctuations in the quality of feed to these plants. However, little direct evidence exists to prove or disprove this suspicion.

In 1985, researchers at CMRC analysed operating data from a coal preparation plant to determine whether a mathematical concept known as "fractals" could be used to reveal the existence of a relationship between feed quality fluctuations and plant yield. Knowledge of such a relationship, assuming it exists, could lead to a method for predicting and controlling the yield.

Normally, mathematical models of random behaviour are based on a phenomenon known as Brownian movement, which is used to explain the random motion of small particles suspended in a fluid. However, random behaviour based solely on the Brownian movement concept cannot account for the severe or long-term fluctuations in feed ash observed at coal preparation plants.

To expand the model, therefore, CMRC researchers proposed to modify the mathematical expressions of Brownian movement by reference to fractal theory. According to this theory, everyday objects like clouds, trees and rocks can never be accurately represented by straight or smooth lines because they have a structure that cannot be approximated by simple geometry. Objects such as these, which possess dimensions but are not integers, are called fractals. When their mathematical representations were combined with mathematical expressions of Brownian movement, the end result was considered to approximate better the more extreme and long-lasting fluctuations of feed ash.

To test this fractal/Brownian model of feed fluctuations, a study was made of a pilot-scale, on-line froth flotation operation. A sampling program was designed specifically to acquire data that could demonstrate the magnitude of feed ash fluctuations and how they affect the yield of prepared coal. This required a specified number of samples that were taken at particular intervals over a 10-hour period. Some samples were obtained as frequently as once every 15 seconds. These samples were then analysed for feed ash. Plots of feed ash versus time were analysed to determine whether the fluctuations represented Brownian movement alone or were more appropriately represented by mathematical expressions of fractal Brownian motion.

It was concluded that the separation efficiency of flotation cells seemed to be affected by feed fluctuations, but this was not strongly supported by the data. Nonetheless, the fluctuations that did occur could be described mathematically as fractal Brownian in nature.

Two attempts were made at establishing a relationship between feed ash fluctuations and product yield by analysing historical operating data from a major preparation plant. In one instance, the data covered an 11-month period, whereas the second set of data was produced over one month. Neither data set provided any evidence that product yield was affected by feed fluctuations. While it was acknowledged that this does not disprove the existence of a relationship, it did suggest that other changes in the plant operating conditions could be equally responsible.

It was concluded that the analytical approach used in this study may be suitable for obtaining meaningful results from a single coal-cleaning device over a short period, but it was not likely to be useful in interpreting historical data from an entire preparation plant.

Washery Optimization

Largely because of their geologic setting, Alberta's mountain and foothills coals have been exposed to forces that cause them to be friable. This means that sizeable amounts of fines are present in these coals. Also, they are more difficult and expensive to clean and recover than coarser coals, but are present in sufficient quantities (up to 40 per cent of the product stream) to justify continual research efforts aimed at minimizing their loss and reducing preparation costs.

The Coal Mining Research Company investigated the suitability of standard tests to measure the performance of gravimetric coal separators used in Alberta coal preparation plants. The merits were reviewed for performing float/sink analyses in a centrifuge, as well as using alternative methods such as density tracers, precision jigging and X-rays. It was recommended that instead of generating partition curves from float/sink analysis, a technique involving discrete float/sink analysis to produce ash downgrade ratio curves should be used. Unlike conventional float/sink analyses, in which an entire sample is tested in each separating fluid in turn, in discrete float/sink analysis, the sample is split into the same number of fractions as separating fluids. One density separation is done on each fraction.

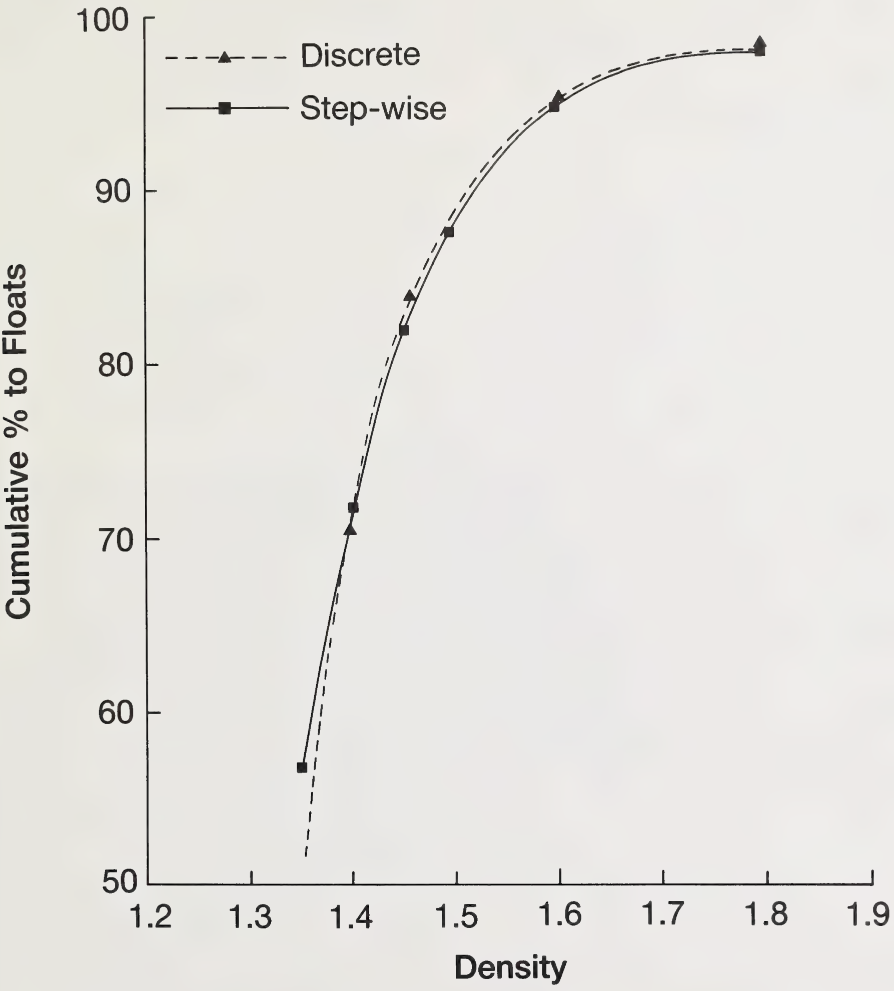
In testing this technique with spiral separators, it was found that performance measurements could be made in half the time required for a standard partition curve performance test. The test results from the ash downgrade ratio curves, however, differed from those produced by partition curves. Also, while an ash downgrade ratio curve test can be performed in less time, it was found that a new curve must be determined each time the feed quality fluctuates. Although this method was satisfactory in Australian pilot-plant studies, it would not be useful in working plants in Alberta that are subject to significant feed fluctuations.

The product quality from a number of spirals tested at random varied considerably. However, the cut points (partition densities) were in a comparatively narrow range. Thus, spirals were demonstrated to be more stable than other separators.

This work was followed by pilot-scale evaluations of a spiral separator unit and a two-stage, water-only, cyclone circuit. The objective was to measure changes in their performance under conditions of fluctuating feed. Samples of raw feed (0.6 x 0.15 mm) were prepared with 20, 30 and 40 per cent ash content. The separators were operated in a closed-circuit (steady-state) mode to obtain the best operating conditions for cleaning the three coal feeds. Then, the separators were operated in an open-circuit configuration. This allowed each separator to receive feed at fluctuating ash contents. The frequency of the controlled feed fluctuations was changed over a 16:1 time ratio in a series of five tests for each separator.

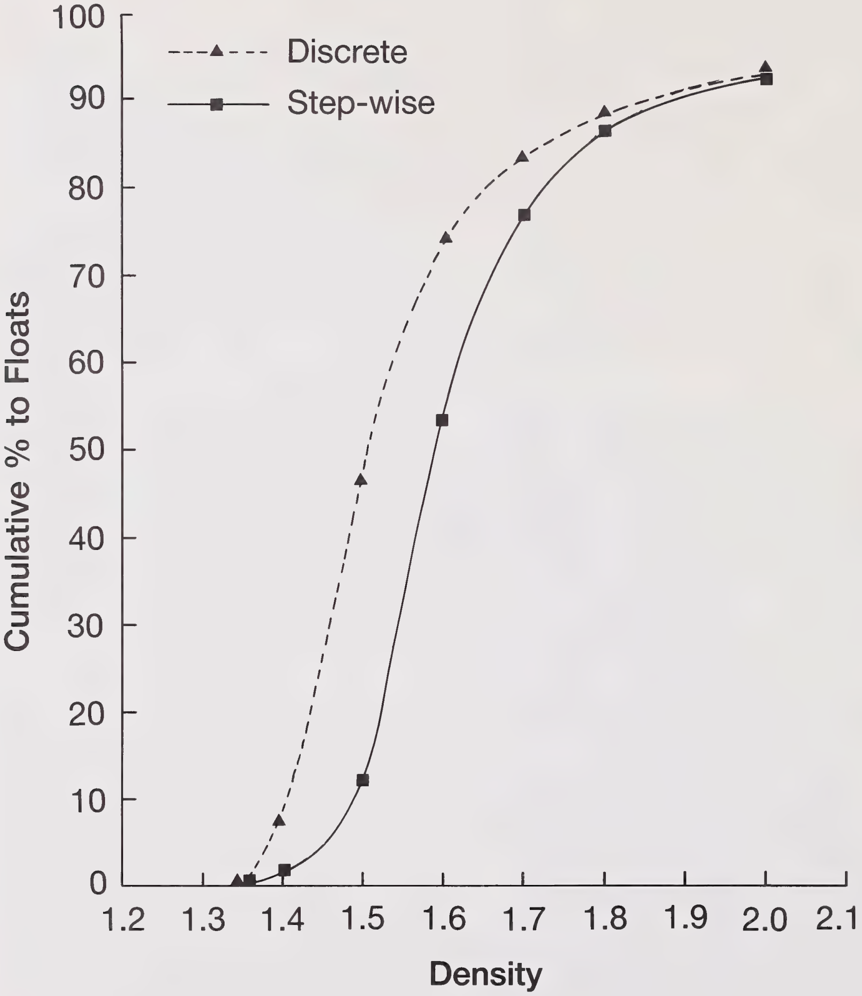
From analysis of the clean coal and rejects, and the use of various methods for measuring the degree of separation under steady-state and fluctuating feed conditions, it was concluded that the steady-state efficiency of each separator was as anticipated from previous literature accounts. However, when both separators were operated under open-circuit, fluctuating feed conditions, the yield losses were at least one-third higher than those obtained in the steady-state, closed-circuit tests. It was also recommended that open-circuit tests should be used when the results are to be used to predict yields.

Results for Low-Volatile Bituminous Clean Coal



(Source: *Washery Optimization: Evaluation of Ash Downgrade Ratio Curves,*
Germain, R.J. and P.S. McIntosh, Coal Mining Research Company, March 1987)

Evaluation of Ash Downgrade Ratio Curves: Results for Subbituminous Coal



(Source: *Washery Optimization: Evaluation of Ash Downgrade Ratio Curves*, Germain, R.J. and P.S. McIntosh, Coal Mining Research Company, March 1987)

Alternative Coal Comminution Methods

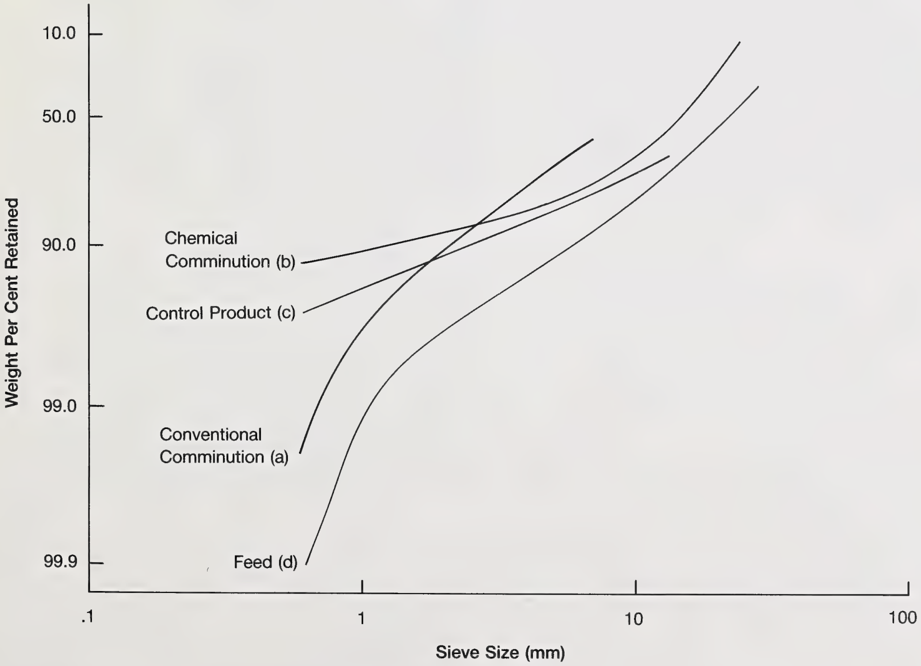
Undesirable mineral matter, which is distributed throughout the carbonaceous component of western Canadian coals, lowers both the energy content and the economic value of these coals to such an extent that it must be removed before coal can be sold in most domestic and international markets.

Currently, these minerals are liberated by crushing to produce particles of various sizes. This is followed by washing. The process of progressively reducing the size of crushed coal particles is called comminution. Normally, it is accomplished by mechanical crushing, which produces a random fracture pattern in the coal. While this liberates some mineral matter, greater quantities of released minerals are desired. Furthermore, crushing has the additional undesirable effect of producing excess amounts of fines.

To determine whether alternative methods for size reduction and mineral liberation might be more suitable for western Canadian coals, researchers at CMRC reviewed the state-of-the-art of coal comminution and experimented with one promising process.

In this study, conventional comminution processes were described and, where applicable, their advantages were highlighted. Included were rotary breakers, impactors, pick breakers, roll crushers, hammermills, cage mills and coal slurry grinding. This was followed by an assessment of non-conventional processes, including Szego milling, cryocrushing, ultrasonic grinding, chemical comminution, comminution with ammonia (gaseous, hydrous or anhydrous), trifluoroacetic acid, sodium hydroxide or methanol, and the use of carbon dioxide/water (CO_2/H_2O) mixtures.

Rosin Rammler Size Distribution Plots of Comminuted Subbituminous B Coal



(Source: *Coal Comminution, Phase 2. Experimental Study Program, Comminution with Carbon Dioxide/Water Mixture,* Rashid, M.A. and T.J. Stuffco, Coal Mining Research Company Report 8661)

Based on impressive results reported in the literature for CO_2/H_2O treatment, it was decided that the response of western Canadian coals to this process should be ascertained. Two types of coal were used: run-of-mine subbituminous B coal and crushed or uncrushed "middlings" of high-volatile bituminous C coal from a commercial coal-cleaning operation.

Using a seven-litre reactor designed and fabricated for this study, coal samples were reacted with carbon dioxide and water for 24 hours at 3 448 kPa (500 psig) to obtain a carbon dioxide concentration of approximately 48 g/L.

Reaction products were evaluated for mineral matter liberation and degree of comminution. Elements present in leachates and ash samples were analysed by atomic emission spectroscopy. The results were compared with those from conventional comminution and a control process in which coal samples were tumbled in deionized water.

Carbon dioxide/water treatment of subbituminous B coal resulted in a product that was coarser than the conventionally comminuted sample. The process liberated mineral matter at recovery rates of up to 95 per cent. Also, the CO_2/H_2O-comminuted coal was weaker and could be broken by hand. Approximately 36 grams of ash per kilogram of ash in the feed were recovered from the leachate. The leached ash was rich in aluminum, calcium, magnesium, iron, silicon, sodium and potassium. It also contained high concentrations of barium, manganese and titanium. It was concluded that CO_2/H_2O treatment could substantially reduce grinding costs if it were used on coal before grinding occurred.

In the case of high-volatile bituminous C coal middlings, CO_2/H_2O treatment did not cause any size degradation of the coal nor did it change the distribution of particle sizes. It leached little mineral matter from the middlings (approximately four grams of ash per kilogram of ash in the feed). Mineral matter leaching was more selective than with subbituminous B coal.

While the results indicated that CO_2/H_2O treatment will not likely replace mechanical comminution in conventional circumstances, its ability to leach certain mineral elements selectively could be useful in developing special-purpose coals. Also, CO_2/H_2O treatment should be considered in situations where fine grinding is used now, such as in the production of liquids from coal.

Coal Ash Monitoring

In an ideal world, totally homogeneous coal would be fed to a coal preparation plant. It would be homogeneous in terms of composition, size and density distribution, which would allow the individual cleaning circuits within the preparation plant to be tuned for maximum profitability.

In the real world, however, the quality of coal varies throughout any deposit. Also, the reliability characteristics of the mining system will vary, as will the degree of process control in the preparation plant. This means that operators of preparation plants must define optimum operating conditions on the basis of factors such as: upstream feed disturbances caused by variations in seam quality and mine production; poor mining methods; the downstream constraints of product specifications; recent production history; and the operator's knowledge of process behaviour. This is a difficult task, but the control function could be made easier through the development of sensors designed to measure coal properties relevant to desired coal quality parameters.

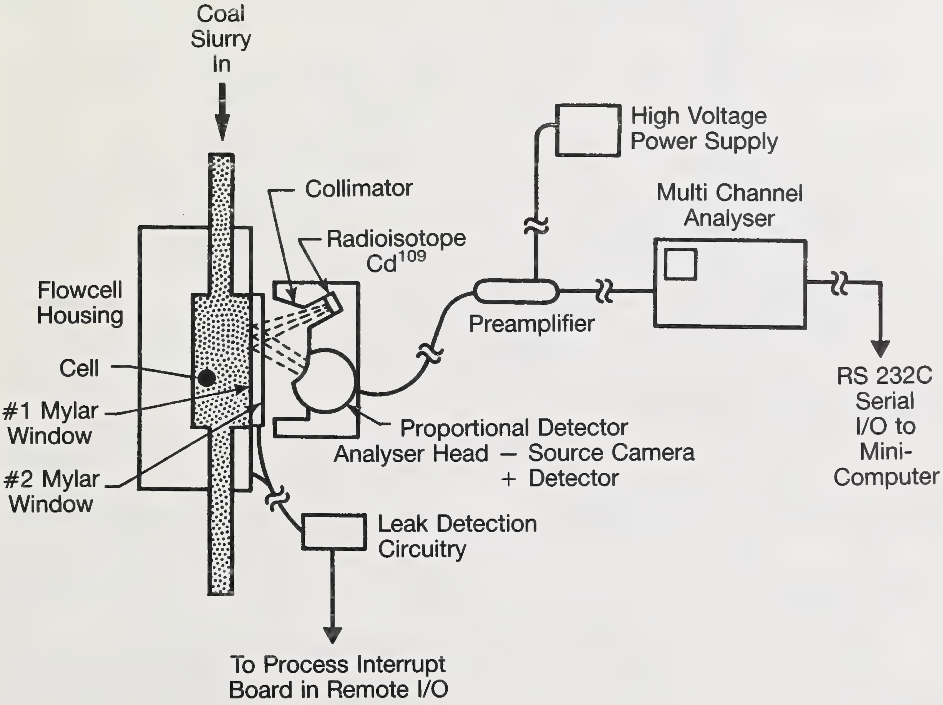
Consequently, a project to develop an on-stream coal ash analyser (OSCAA) for fine coal slurries was initiated at the University of Alberta. The first phase involved verifying the potential benefits achievable through improved monitoring and control. To simulate the output from an on-stream analyser, the flotation circuit was sampled at high frequency over a 20-hour period. From the results, it was determined that substantial savings were possible because of the reduced production losses that result from greater stability in the operation.

After reviewing the literature concerning commercially available on-stream ash analysers, it was decided that the OSCAA would employ a radioisotope measuring system. The device comprises three subsystems: one for sample presentation; one for pulp density measurement; and one for backscattered and fluorescent radiation measurements. The pulp density subsystem employs a gadolinium-153 radioisotope, whereas the backscatter/fluorescence subsystem used for ash analysis uses a cadmium-109 radioisotope.

The system was calibrated in a laboratory with slurries of flotation concentrate and flotation tailings from the Smoky River Mine. Each coal source was analysed in the conventional manner for ash content, iron concentration of the ash and specific gravity of solids. The data were used to develop empirical models that allowed the per cent solids and ash in coal slurries to be calculated from the radioisotope measurements. The results from this phase of the study indicated that the OSCAA system was capable of providing process control of the fine coal circuit at the Smoky River Mine.

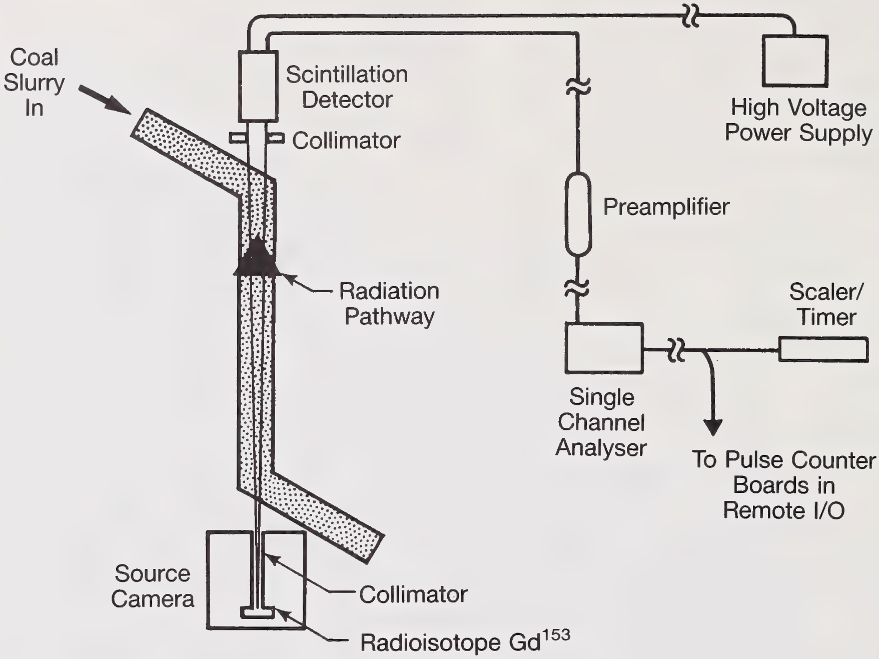
A plant trial was undertaken, using the concentrate stream from the #4 bank of flotation cells. Even though the pulp density subsystem did not perform properly, the plant calibration trial was deemed successful.

Schematic of the OSCAA Ash Analysis Subsystem



(Source: *Modelling and Control of Coal Beneficiation Unit Operations,*
Plitt, L.R. and B.C. Flintoff, Department of Mineral Engineering, University of Alberta, 1983)

Schematic of the OSCAA Pulp Density Subsystem



(Source: *Modelling and Control of Coal Beneficiation Unit Operations,*
Plitt, L.R. and B.C. Flintoff, Department of Mineral Engineering, University of Alberta, 1983)

Moisture and Ash On-Stream Analysers

It is generally believed that one way to introduce more effective control of coal cleaning plants is to use devices capable of continuously monitoring the moisture and ash contents of incoming coal. Such devices must be capable of providing results quickly so that operators can make changes to processing conditions in response to differences in coal composition. Also, a degree of accuracy at least comparable to existing, standardized tests for moisture and ash content is desirable.

CMRC researchers undertook a review of the literature on coal ash and moisture analysers. The measurement principles used in existing devices were examined. These included: electromagnetic radiation, neutron activation and coal slurry systems used for ash; and various on-line moisture measurement concepts based on properties such as capacitance, microwave generation, infra-red reflection and conductivity.

The review included a wide range of commercially available analysers, as well as analysers installed in Canadian coal preparation plants. The attributes of 17 analysers were examined. It was concluded that a belt-mounted, low-energy transmission ash monitor and a microwave attenuation moisture meter should be tested at a western Canadian coal mine and compared with devices already installed at two other mines.

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